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LA-UR- 88-1957

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LA-UR--88-1957

DE88 014441

TITLE: SUMMARY OF NEUTRINO PRESENTATIONS

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SUBMITTED TO: The 3rd International Conference on the Intersections
between Particle and Nuclear Physics, May 14-19, 1988,
Rockport, Maine

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SUMMARY OF NEUTRINO PRESENTATIONS

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ABSTRACT

This summary is divided into two sections. First, we concentrate on conventional neutrino physics interpreted in the context of standard electroweak theory. Second, we discuss double beta decay where gross violations of the predictions of the theory might appear, and also we discuss specific searches for consequences of finite neutrino mass.

SUMMARY

I. Two measurements were reported at this meeting of interaction cross sections of neutrinos on nuclei ^{12}C . The first, reported by X-Q Lu used the 800 MeV proton beam at LAMPF to produce an intense source of neutrinos through π^+ production and decay and also through subsequent μ^+ decay in the beam stop. The experiment was designed to measure neutrino-electron scattering and verify that the interference between charged and neutral-current contributions is destructive as predicted by the standard model. In addition the background to this measurement is due to charged-current scattering on carbon in the detector and so a measurement of this cross section was made. An additional trick allowed isolation of the scattering to the ^{12}N ground state; ^{12}N beta decays with a 16-ms lifetime and an end-point energy of 15 MeV, so that the decay electron is readily observable in the detector. In Fig. 1 is shown the time distribution of pulses following an electron event with beam on and

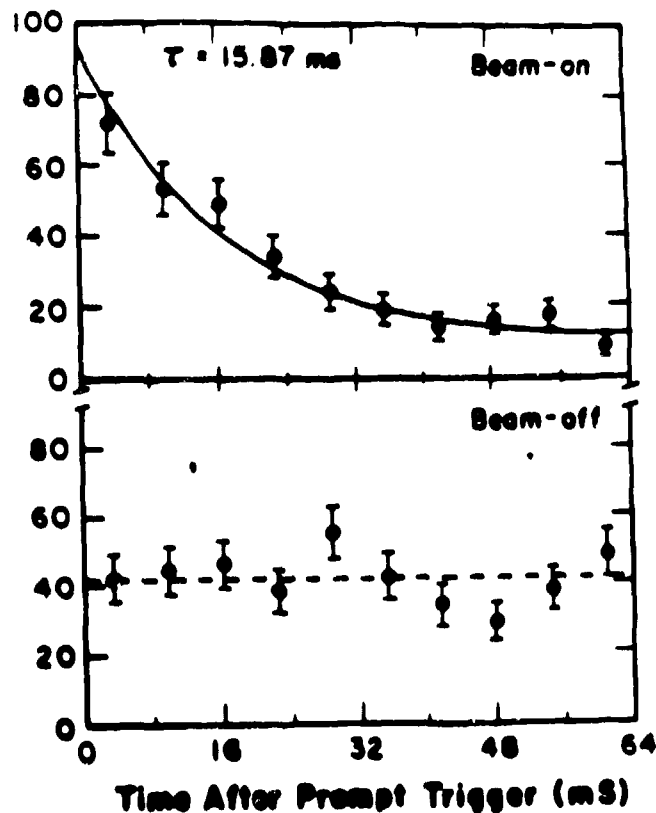


Fig. 1

beam off. The presence of the 10 ms component of beam on data is apparent. The neutrino flux is known from calculation, and so an absolute cross section is determined. There has existed a calculation of these cross sections in the literature by T. W. Donnelly for some time and the measured rates are compared with the calculation in Table I. The agreement is satisfactory although, now that data are available, perhaps further refinement of the calculation may be expected.

TABLE I

Measured Cross Sections

$$\sigma_{gs} = (1.25 \pm 0.11 \pm 0.14) \times 10^{-41} \text{cm}^2$$

$$\sigma_{inc} = (1.85 \pm 0.22 \pm 0.23) \times 10^{-41} \text{cm}^2$$

T. W. Donnelly Calculation

$$\sigma_{gs} = 0.94 \times 10^{-41} \text{cm}^2$$

$$\sigma_{inc} = 1.31 \times 10^{-41} \text{cm}^2$$

Robert Manweiler reported on a second experiment that is similar in some ways except that the neutrinos are derived from decay of pions in flight, also at LAMPF. The neutrinos are higher in energy, typically 150 MeV. Events are detected by observing the muon decay after coming to rest. The range of the final-state muon is small, and the decay electron gives a muon lifetime shown in Fig. 2 for both exclusive events, i.e., to the ground state of ^{12}N as above, and to all final nuclear states. The inclusive events have a small background, but the reactions leading to the ground state seem particularly clean. The muon kinetic-energy distributions shown in Fig. 3 are similar for both reaction classes. Recall that the muon kinetic-energy distribution is a little less than 105 MeV below the incident-neutrino energy. Again the neutrino-energy distribution and absolute flux are calculated, and then a cross section is derived. In Table II is shown a comparison of cross section with calculation.

TABLE II

$$\sigma(\nu_{\mu} + ^{12}\text{C} \rightarrow \mu^{-} + \text{X}) = (10.9 \pm 1.8) \times 10^{-39} \text{cm}^2$$

Process	Events	σ_{exp}	σ_{theory}	
Inclusive	63	10.9 ± 2.8	8.2	(DW & O'Connell)
$^{12}\text{N}(\text{g.s.})$	19	3.4 ± 1.6	0.08	(Donnelly)

The inclusive cross section seems reasonable, but the Donnelly calculation predicts that the experiment would not have seen any exclusive events and 3.4 ± 1.6 are seen. This is a somewhat troubling situation, although the experimental statistical precision is limited.

At Brookhaven, a program to measure $\nu_{\mu} - e$ scattering to determine the electroweak mixing angle is complete. Milind Diwan reported on the results of the final

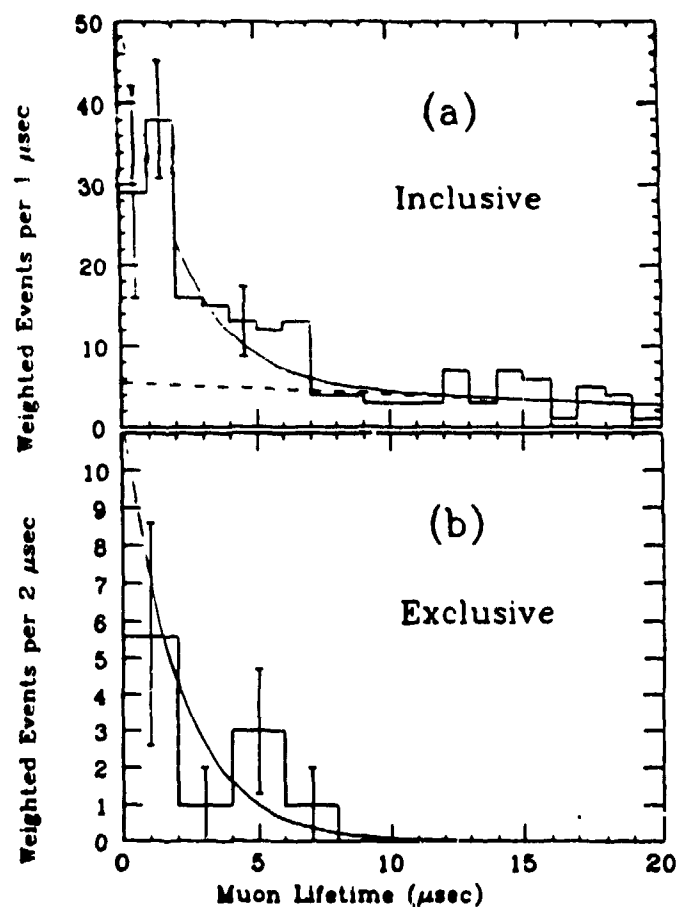


Fig. 2

Muon Kinetic Energy Distribution

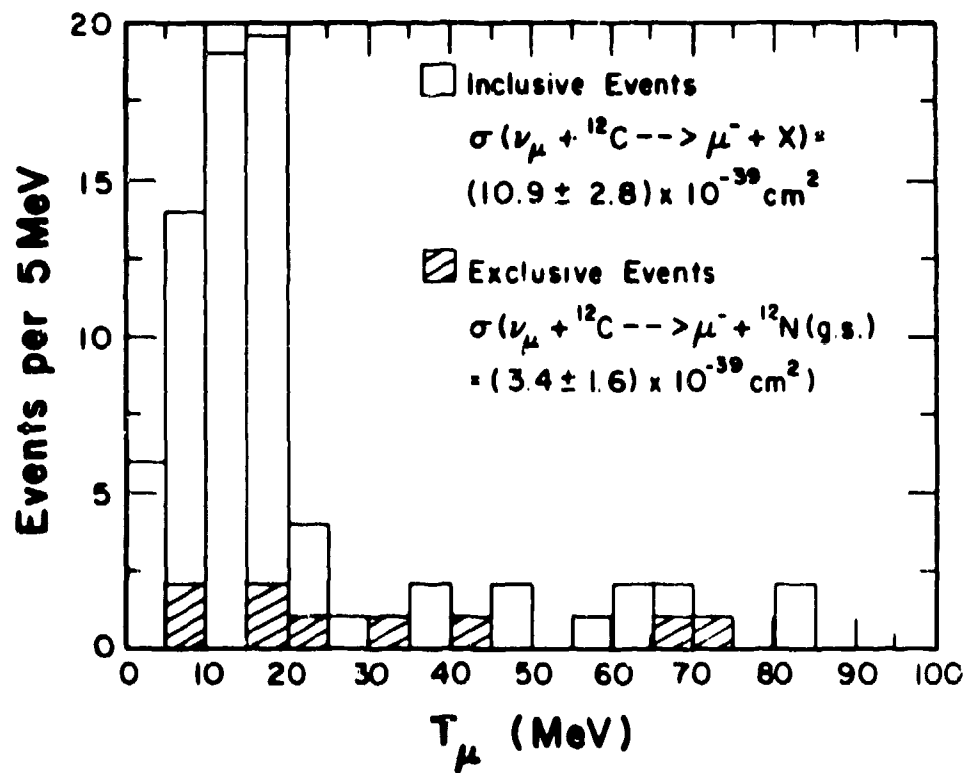
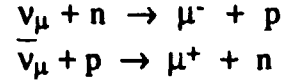


Fig. 3

analysis. The beam is from a decay-in-flight source, and events are detected in a highly segmented detector with capability to isolate recoil electrons and measure angle and energy. Neutrino-electron-scattering events are identified by the smallness of the angle of the recoil electron and the neutrino direction; this distribution is shown in Fig. 4. The signal peak at small angles is clear and the cross-section ratio for neutrino and antineutrino scattering is made with precision. This group now has as many events as all previously published data, although more data are expected from CHARM II shortly. In order to normalize the individual neutrino and antineutrino cross sections quasi-elastic scattering



was used, for events predominantly at low Q^2 . The event sample is shown in Table III together with the beam energies for both neutrinos and antineutrinos.

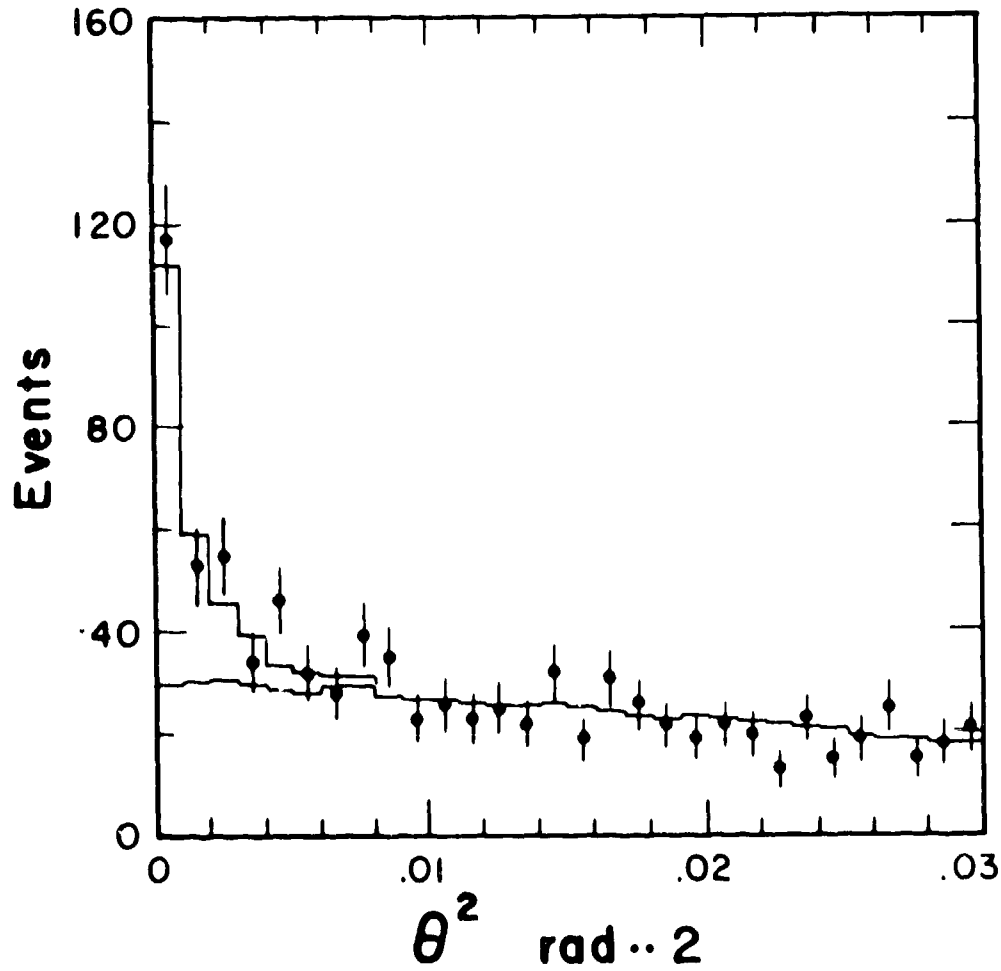


Fig. 4

TABLE III

<u>ELECTRON</u>	ν_μ	$\bar{\nu}_\mu$
observed	$159.5 \pm 17.3 \pm 7.3$	$96.7 \pm 13.2 \pm 8.8$
efficiency corrected	$322.6 \pm 35.5 \pm 24.5$	$163.3 \pm 22.6 \pm 16.8$
<u>MUON</u>		
observed	79082	59241
efficiency corrected	$10.1 \times 10^5 (12.3\%)$	$4.26 \times 10^5 (8.6\%)$
<u>BEAM</u>		
$\langle E_n \rangle$	$1.274 \pm 0.022 \text{ GeV}$	1.227 ± 0.022
$\langle \sigma(QE) \rangle$	0.919×10^{-38}	0.381×10^{-38}

The value of $\sin^2\theta_w$ is

$$0.197 \quad + 0.020 \pm 0.017 \quad , \\ - 0.021$$

which is to be compared with $0.228 \pm 0.007 \pm 0.002$ from the masses of W and Z and $0.233 \pm 0.003 \pm 0.005$ from deep-inelastic neutrino scattering. These numbers come from the compilation of Amaldi et al.¹ It is probably too early to worry about a possible discrepancy, but the universality of $\sin^2\theta_w$ after radiative corrections is indeed a cornerstone of the electroweak theory.

II. It is assumed in the standard electroweak model that the mass of the neutrino is zero. This is primarily to assure that neutrinos are left handed and the right-handed sector is absent. Boris Kayser presented a challenge to this point of view and pointed out that there are good reasons to expect neutrino masses to be small, but not zero. The seesaw model gives reason for neutrino masses to be very tiny compared to present measurement capability. The conventional Dirac neutrino also came under scrutiny with a strong possibility that neutrinos may be Majorana; their own antiparticle. This array of physical possibilities makes the neutrino a very interesting particle, although classically difficult to study. Information on neutrino mass can come from the following topics

1. β decay
2. ν oscillations
3. $\beta\beta$ decay
4. Solar neutrinos
5. Supernovae.

There were presentations on Topics 1, 2, 3, and 4 in this neutrino session.

John Wilkerson discussed the state of experiments seeking to observe evidence of finite neutrino mass in tritium beta decay



There are a large number of efforts devoted to this problem; they are summarized in Table IV.

TABLE IV
TRITIUM EXPERIMENTS

<u>Investigator</u>	<u>Location</u>	<u>Spectrometer</u>	<u>Source</u>
+Lyubimov	Moscow	Toroidal Magnet	Valine-T
+Kundig	Zurich	Toroidal Magnet	C-T
+TJB,RGHR,JFW	Los Alamos	Toroidal Magnet	T,T2 gas
+Ohshima	Tokyo	p2 Mag	"Acid"-T
Fackler	Livermore	Retarding E-S	T2 solid
Clark, Frisch	IBM	Retarding E-S	?
Jelley	Oxford	Cylindrical Mirror	Ca-Palmitate-T
+Sun	Beijing	Iron Core Magnet	LiT,PdT,organic
Lobashov	Moscow	Retarding E-S	T,T2 gas
Stoeffl	Livermore	Toroidal magnet	T,T2 gas
Daniel	Munchen	Iron Core Magnet	Hf-T
Boyd	Ohio State	Retarding E-S	?
Wellenstein	Brandeis	Cylindrical Mirror	T2 Gas
Kalbfleisch	Oklahoma	?	?
Otten	Mainz	Retarding E-S	T Gas
Derbin-Popeka	Leningrad	Si	Si-T
*Simpson	Guelph	Si	Si-T

* Experiment Completed

+ Have Results

The reason that all this activity is occurring is that there has been a positive result from the Lyubimov group for some time; the data are shown in Fig. 5.

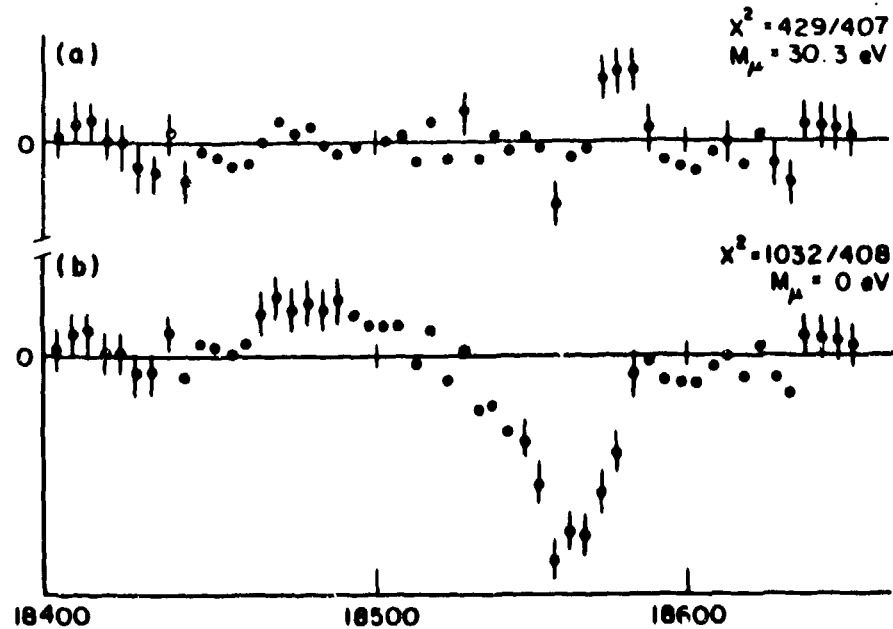


FIG. 5

Statistically, the finite-mass effect is clear, but of course all the problems of these experiments are systematic. The statistical precision is critically dependent on a background-free experiment. It is unfortunate that the groups that have opted to use electrostatic spectrometers have suffered with more background than the magnetic-spectrometer experiments. As an example of the differences between experiments, the resolution functions of a number of experiments are shown in Fig. 6, with low-energy tails in these functions from energy loss in the target depending on the final molecular states and, hence, the structure of the target material. John Wilkerson emphasized the advantage of a gaseous source of T_2 and we look forward to more data from the Los Alamos group. The consensus seems to be that the electron-neutrino mass is certainly below 35 eV, but a mass in the eV range is still open.

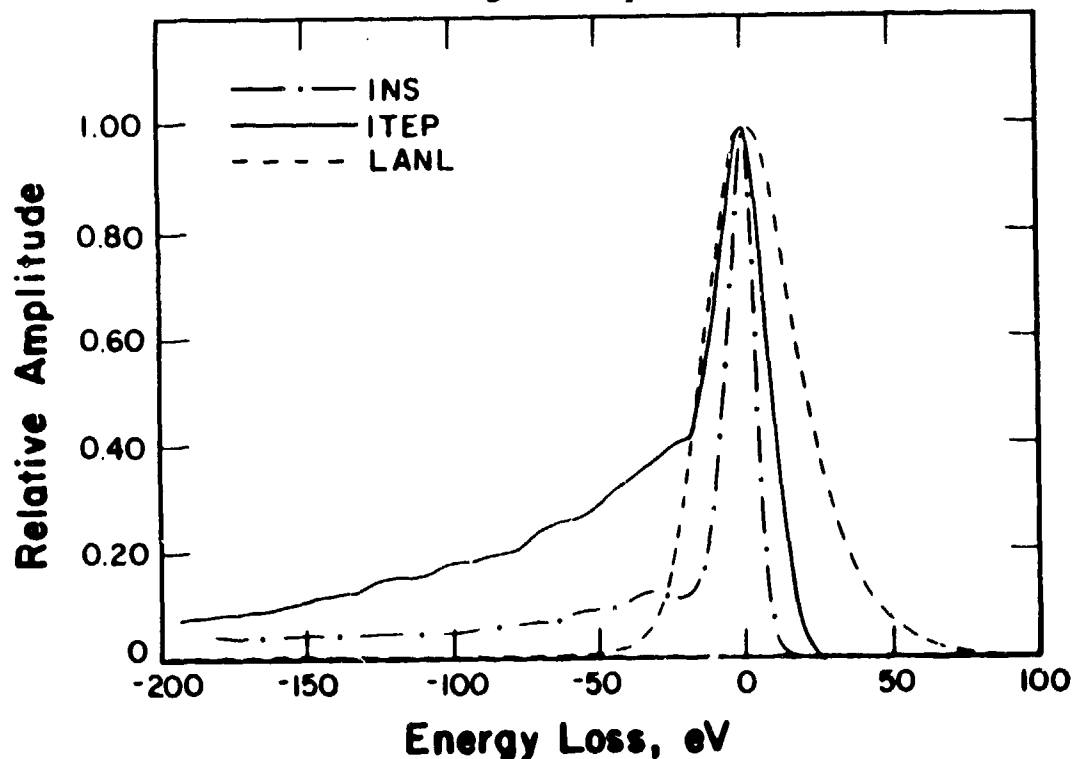


Fig. 6

Two experiments were presented searching for neutrino oscillations. Richard Seto presented data from a Brookhaven narrow-band beam in which oscillations of the type $\nu_\mu \rightarrow \nu_e$ would appear as anomalous charged-current events with electrons in the final state. The energy spectrum of the identified electron events is shown in Fig. 7a with the Monte Carlo estimate in Fig. 7b. The experimenters conclude there is no evidence for anomalous events leading to the limits shown in Fig. 8. Stan Durkin showed data from a Los Alamos measurement, which looked for $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ oscillations. At the beam stop at LAMPF there are no $\bar{\nu}_\mu$ because π^- are all absorbed before decay. Moreover, ν_e charged-current interactions on ^{12}C are suppressed relative to ν_e on free protons and cut off at a lower energy. In Fig. 9 is shown a distribution of identified electron energies in the detector with a Monte Carlo estimate of the expected rate assuming no $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$ oscillations. The limit implied by this measurement is similar to that in Fig. 8. Further running by this experiment might improve the limit by about a factor of two.

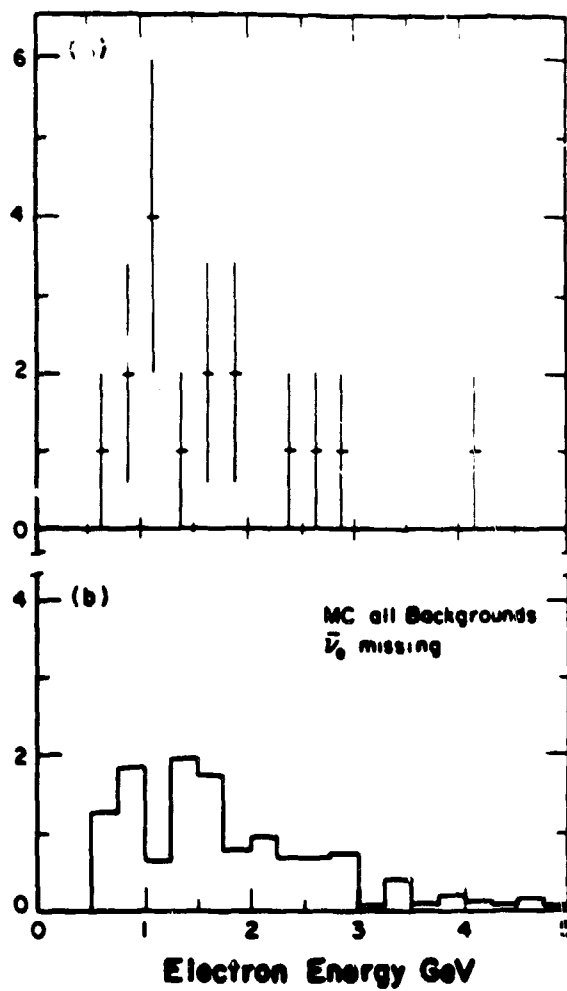
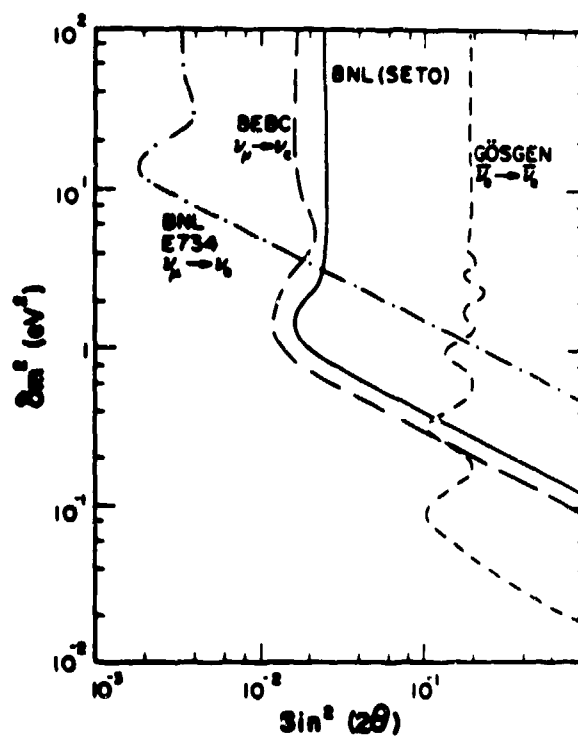


Fig.7(a)

Fig.7(b)

Fig. 8



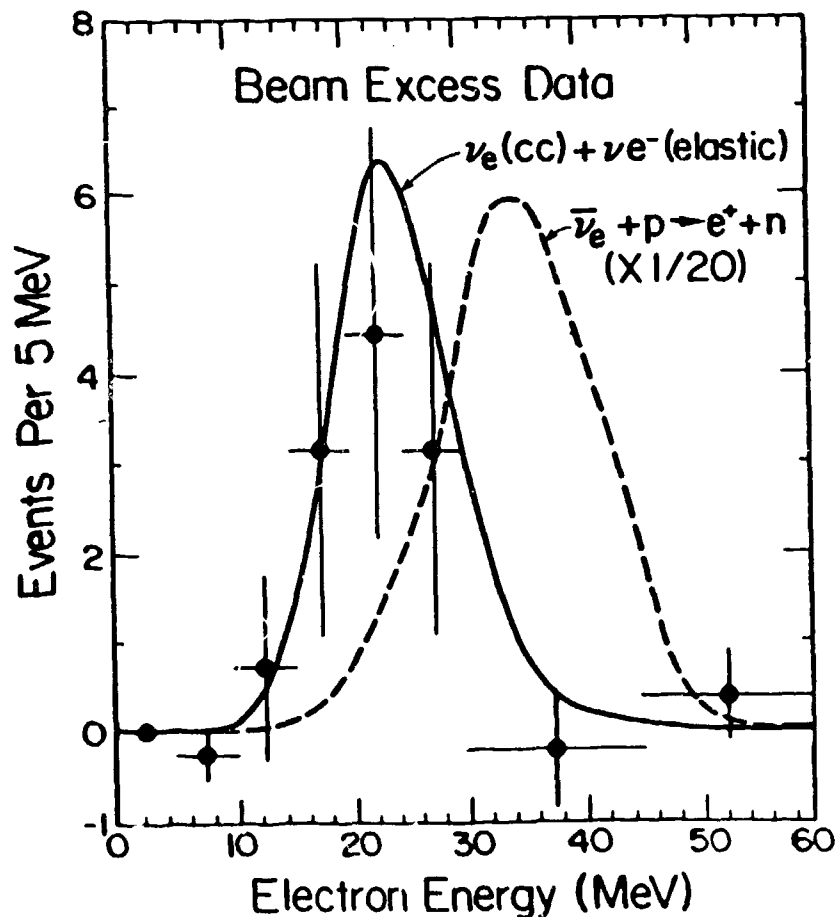


Fig. 9

Double beta decay with two neutrinos in the final state is a process that is expected to occur conventionally in the standard electroweak theory. In the case that single beta decay is forbidden by energy conservation then double beta decay is observable when two nucleons participate in the transition. It has been assumed that these two transitions are independent and that the rate is given by the nuclear matrix element with a second-order weak transition. A problem with this view is that geochemical studies in tellurium have indicated that the decay rate is substantially weaker than expected from a calculation by Haxton and Stevenson. Williams presented a calculation done with Haxton in which the axial-charge term was included and noted to interfere destructively with the principal transition terms. However, this term is too small to account for the Te discrepancy, although it is a step in the right direction. Stevenson made some general remarks that in calculating nuclear matrix elements for double beta decay the correlations between nucleons should be taken into account at least, because double charge exchange has shown the correlations to be significant. In the context of this problem the Irvine experiment on ^{82}Se presented by Alan Hahn was very interesting. This experiment uses a Time-Projection Chamber to reconstruct the tracks from the two electrons in the double-beta-decay transition. The sum of the two electron energies is shown in Fig. 10 for two versions

Sum Spectrum Comparison

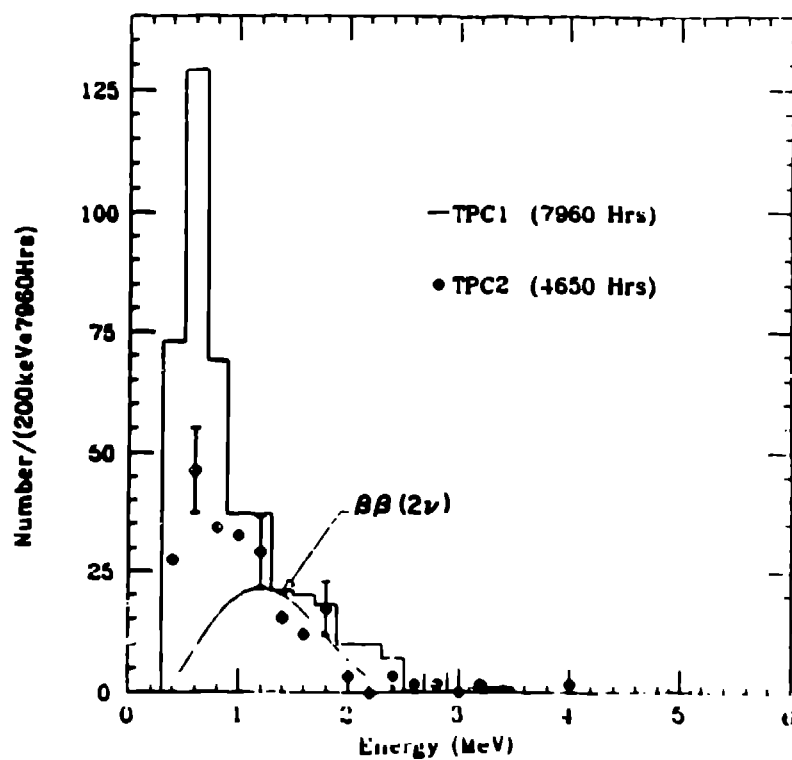


Fig. 10

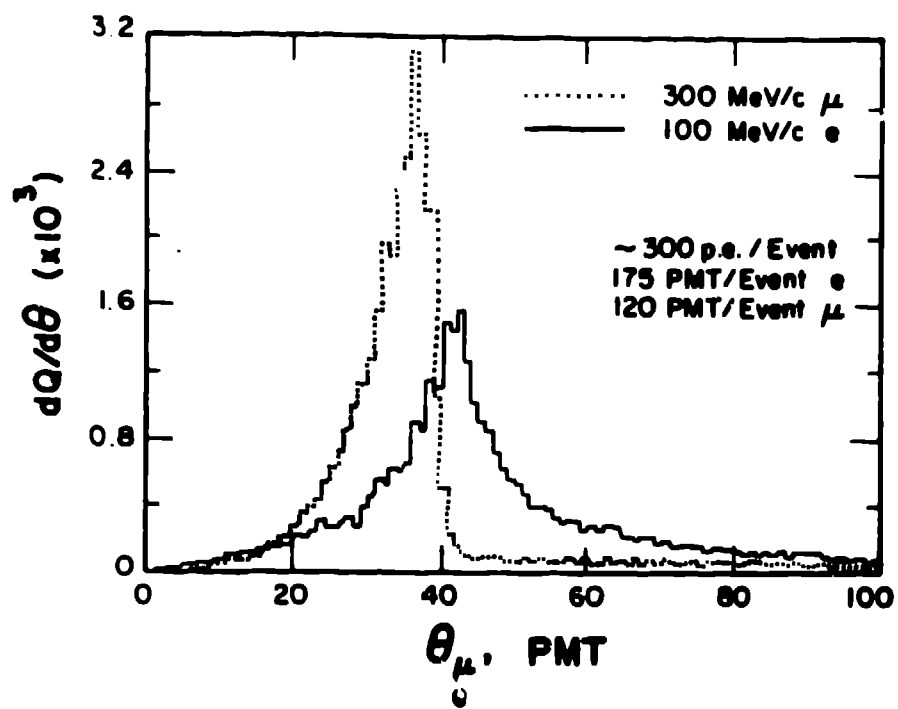


Fig. 11

of the apparatus; TPC 2 is a lower-background experiment and a fit to the spectrum gives the curve $\beta\beta(2\nu)$ for the decay. The lifetime from this fit is

$$\tau(2\nu) = (1.4 \pm 0.6 \pm 0.3) \times 10^{20} \text{ yrs}$$

This value is in approximate agreement with theoretical estimates of the rate, and the Te puzzle remains. Frank Avignone gave a summary of the double-beta-decay work in progress, mentioning in particular the ^{76}Ge experiments looking for neutrinoless decay, notably the UC Santa Barbara - LBL collaboration, which has the highest limit at the moment of 7×10^{23} yr. For neutrinoless double beta decay to occur, the neutrino mass must be non-zero and right-hand currents must exist. Major mischief to the standard model would result. The flurry of interest in a possible observation of double beta decay with a majoron has subsided.

A puzzling observation by the Kamioka-II collaboration was reported by William Frati. Fully contained neutrino events are observed in the Kamioka detector that are produced by cosmic-ray interactions in the atmosphere. In simple terms, since the $\pi\mu$ decay chain produces two ν_μ and one ν_e , then it is expected that twice as many muon events over electron events would be seen. Detailed effects reduce this number to somewhat close to unity, according to the standard calculation of Gaisser et al. Muons in the detector produce a different ring pattern to electrons largely because multiple scattering is different at the same deposited energy as shown in Fig. 11. Separation of the two classes of events in this energy range is straightforward. In Table V are shown the data for an exposure of 2.87 kiloton-years with $p_e > 100 \text{ MeV/c}$ and $p_\mu > 200 \text{ MeV/c}$.

TABLE V

	DATA		MC	
	Total	μ decay	Total	μ decay
Single Ring	178	60	235.5	110.3
m-like	85	52	144.0	103.8
e-like	93	8	8.5	6.5
Multi Ring	<u>87</u>	<u>34</u>	<u>86.2</u>	<u>37.1</u>
Total	265	94	318.7	147.4

The ratio for muon-to-electron events for data divided by the same ratio for Monte Carlo is 0.56 ± 0.08 . If the cut on momentum is made equal for electrons and muons at 200 MeV/c then this ratio changes to 0.53 ± 0.08 . Beier pointed out in the question period that before too much is made of this result, a concern he communicated about the calculation of cosmic ray neutrino flux should be alleviated.

Finally, Balentekin described an analytical method for calculating the solar neutrino flux in the case that the MSW effect is important. The calculation is straightforward and offers significant saving of time for a wide range of mass-difference squared and mixing parameters.